Development of Ecological Indicator Guilds for Land Management

CS-1114B

Research Team

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TAC Review: 7-9 October 2

Technical Objective

Develop Ecological Indicators To:

- Quantify habitat condition and trends
- Track and monitor ecological changes
- Provide early-warning or threshold detection
- Provide guidance for land managers based on ecological realities and statistical rigor

Ecological Indicator Design Criteria

Modified from Proposal, Table 1 (1998)

- Ease of use for land managers
- Cost effective
- Ecological relevance & value
- Reflect ecosystem dynamics and physiological stress
- Quantifiable with statistical estimates of accuracy & precision
- Robust & multi-scale
- EcoRegion application
- Global methodology extension
- Symmetry: track degradation & recovery/restoration
- Reasonable response times
- Reliable, consistent, unambiguous
- Incorporation of natural variance
- Known sensitivity to temporal sampling window
- Association with suites of stressors

Site Selection Criteria

Fort Benning, Georgia

- **Similarities among sites**
  - **Physiography Upland Sandhills**
  - **Vegetation Mixed Pine/Hardwoods Forest**
  - **Soils Sandy Loam**
  - **History Agriculture – pre 1940s**
  - **Spatial 2 Adjacent Watersheds**
- **Differences among sites**

  ***Disjunct* Military Training Land-Use**

  Three Disturbance Classes
  - **High**
  - **Medium**
  - **Low**

Site Selection (cont.)

- **Selection Process**
  - Fort Benning Personnel Experience and Expertise
    Pete Swiderek, Theresa Davo
  - Field Experience of Research Team
- **9 Research Sites in Two Watersheds**
  - Bonham Creek: 2 pairs of Low, Med, High
    L1, L2 - M1, M2 - H1, H2
  - Sally Branch: 1 pair of Low, Med, High
    L3 - M3 - H3
- **Habitat Sampling**
  - Centered on upland lysimeters
  - Sampling Plots: 0.36 hectare

Site Selection Based on a Disjunct Landscape Disturbance Gradient

3 sites selected in each disturbance

High

Current mechanized-in training activities

H3

H1

Medium

Past training activities
Current foot traffic

M3

M1

Low

No military vehicles
Minimal foot traffic

L2

L1

Research Approach 2000 – 2001 – 2002

- **Potential Ecological Indicator Systems (EISs)**
  - **Based on Individual, Population, Community, Ecosystem, (Landscape), Parameters**
  - **Experience/Expertise of Team & Literature**
- **Selected Ecological Indicator Systems (EISs)**
  - **Field Measured Responses at 9 Sites To:**

    Ecological Processes, Structure/Composition, Physiology
- **Promising Ecological Indicator Guilds (EIGs)**
  - **Discriminant Analysis of Each EISs with Respect to a Disjunct Landscape Disturbance Gradient**

Selection & Analysis of Ecological Indicator Systems

EIS Class	Reviewed	Field Tested	Promising
Terrestrial Plants, Habitat Metrics	23	14	2
Terrestrial Animals	21	11	1
Soils & Microbial	29	5	3
Aqu./Rip. Animals	10	2	0
Aquatic Plants	0	0	------
Hydrology, Abiotic Aquatic	20	0	------
TOTAL	103	32	6

Promising Ecological Indicator Guilds (EIGs)

1) Habitat Characterization
2) Ground Cover
3) Ground Ant Community
4) Microbial Community
5) Soil Chemistry
6) Soil Mineralization Potential

Additional Ecological Indicator Systems

Nutrient Leakage **(an excellent indicator)**

- **Lysimeters (Upland – Lowland Combinations)**
- **Trench Plots**

But, labor and time intensive

Developmental Instability was sensitive to:

- **Fire**
- **Drought**
- **Insect Damage**

Variance was very high and labor and time intensive

Habitat Ecological Indicator Guild

23 to 2 Variables

- A-Horizon Depth
- Soil Compaction
- Soil Shear Stress
- Canopy Cover
- Tree Density
- Basal Area (7 vars.)
- Mean DBH
- Std. Dev. DBH
- Bare Ground *
- Pine Litter
- Deciduous Litter
- Pine Seedlings
- Total Forb Cover
- Legume Cover
- Grass Cover
- Woody Cover
- Woody Species Richness

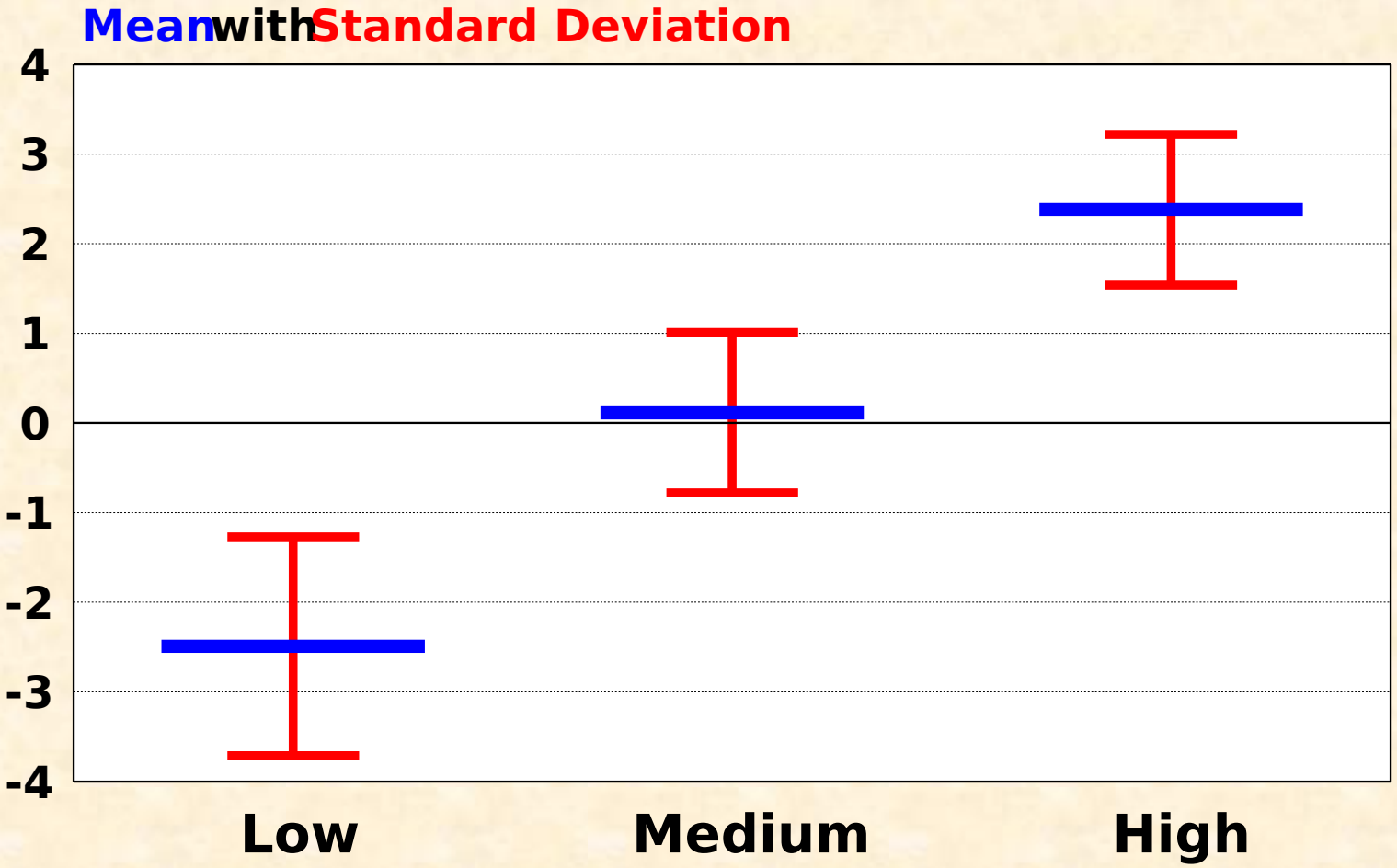
* Redundant

Other Five Ecological Indicator Guilds

- **Ground Cover**
  - General Ground Cover Metrics
  - 126 Taxa to 9 Species
- **Ground Ant Community**
  - 48 Species to 28 to 6(5) Species
- **Microbial Community**
  - Microbial Biomass Carbon
  - Functional Diversity
  - Total Activity
- **Soil Chemistry**
  - NO_3 NH_4 Organic Carbon
- **Soil Mineralization Potential**

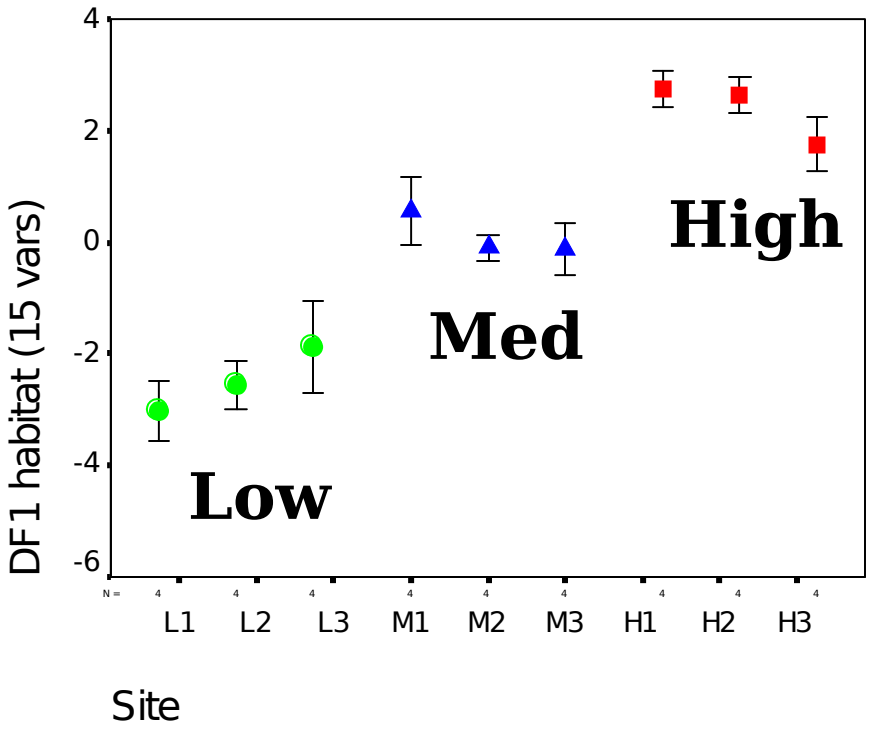
Habitat EIS DF1

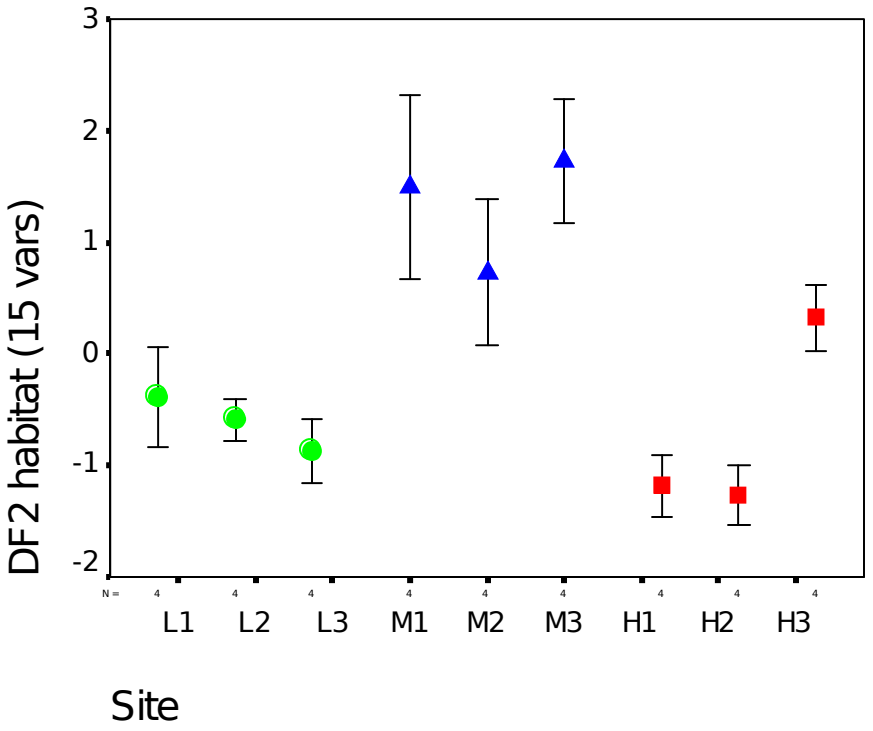
(15 Habitat Variables)



Habitat EIS

15 Habitat Variables



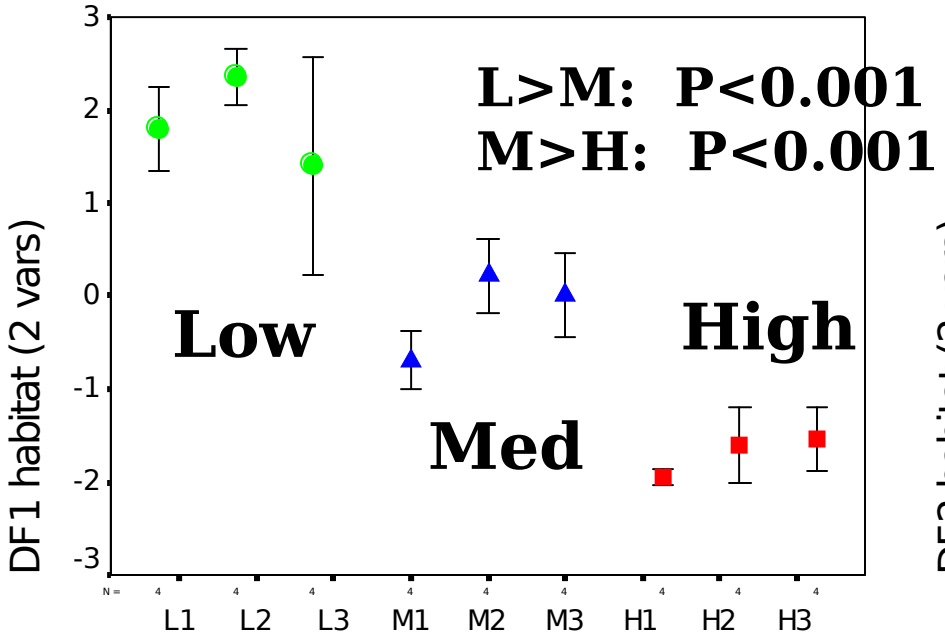


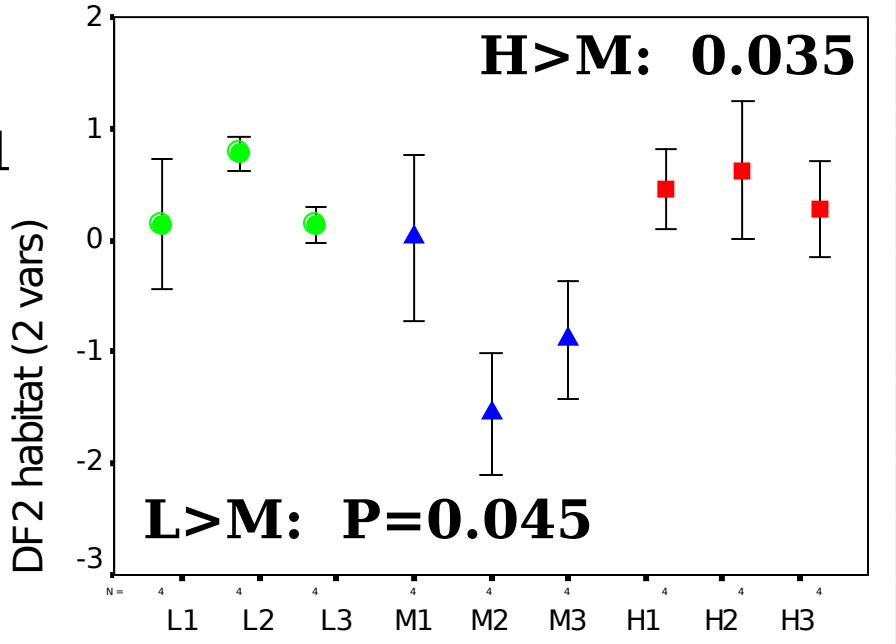
DF1
Mean with SE

DF2
Mean with SE

Habitat EIG

A-Horizon Depth & Soil Compaction





DF1

Mean with SE

DF2

Mean with SE

Ground Cover Ecological Indicator Guild

from 126 original taxa to 9 species

Sampling: **tree seedlings, shrubs, woody vines,**

perennial & annual forbs and grasses

Pteridium aquilium, Opuntia humifusa,

Yucca filamentosa

- **Tree Seedlings**

  Cornus florida, Sassafras albidum

- **Shrubs**

  Rubus cuneifolius, Vaccinium arboretum

- **Woody Vine / Ground Cover**

  Rhus radicans

Ground Cover Ecological Indicator Guild

- **Perennial Forb**
  Aster patens
- **Perennial Legume**
  Clitoria mariana
- **Perennial Bunch Grass**
  Andropogon virginicus
- **Annual/Biennial Forb**
  Gnaphalium purpureum

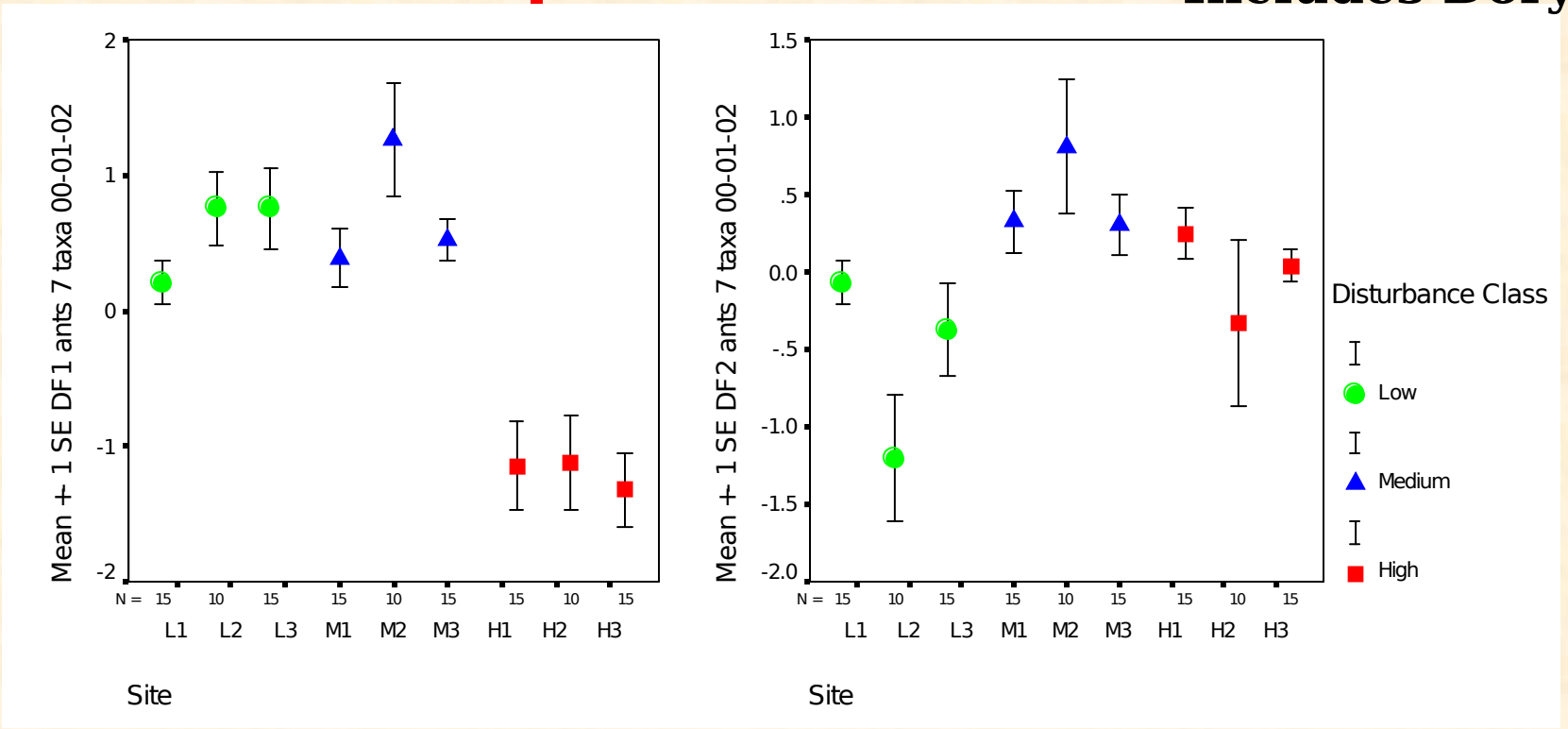
How reliable is this Ecological Indicator Guild?

Original Analysis of Ground Ant Community EIG

28 Original Species (2000, 2001, 2002)

7 Ant Species in Final Guild

Includes Dorymyrm



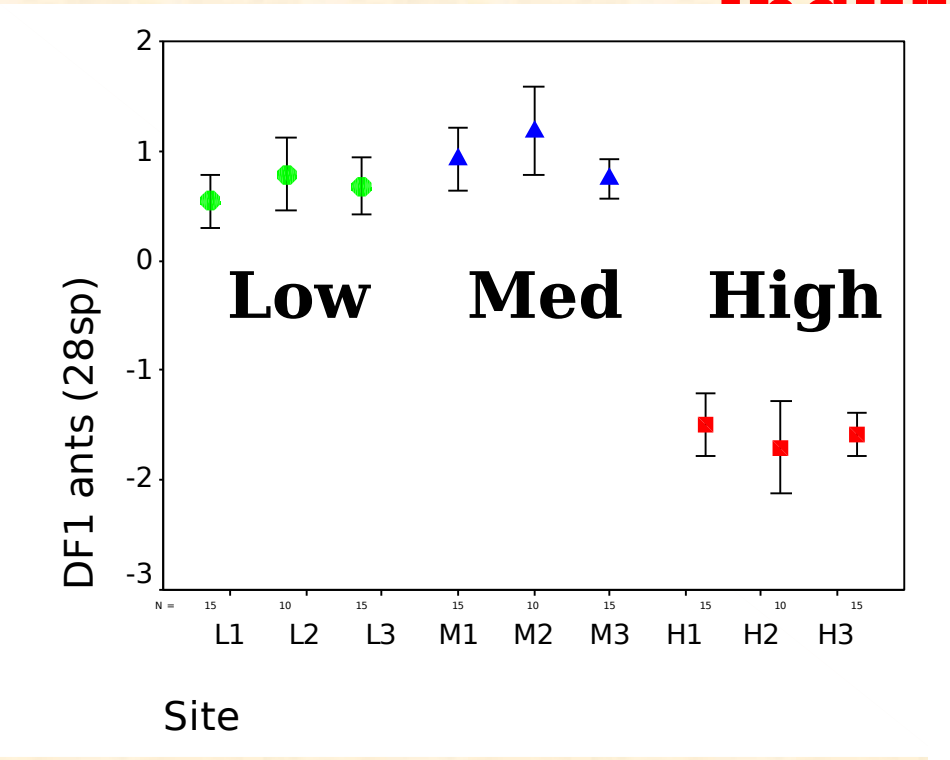
DF1 **DF2**

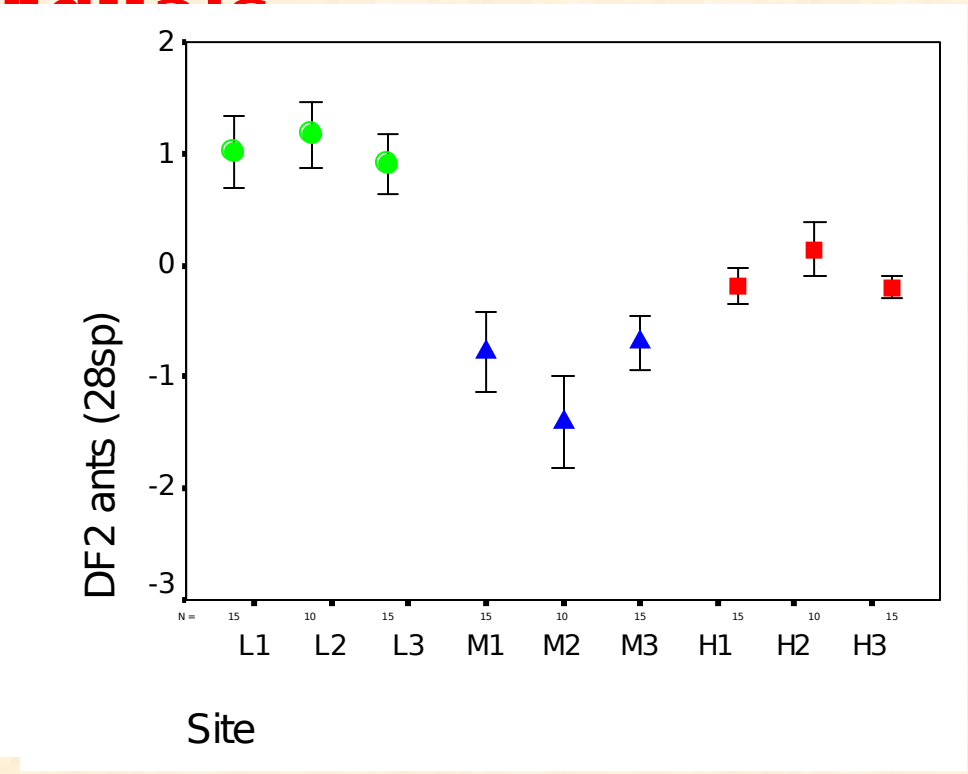
New Analysis of Ground Ant Community EIG

48 Initial Species (2000, 2001, 2002)

28 Species in Analysis, N=103,203

Dorymyrmex smithi = 87% of individuals





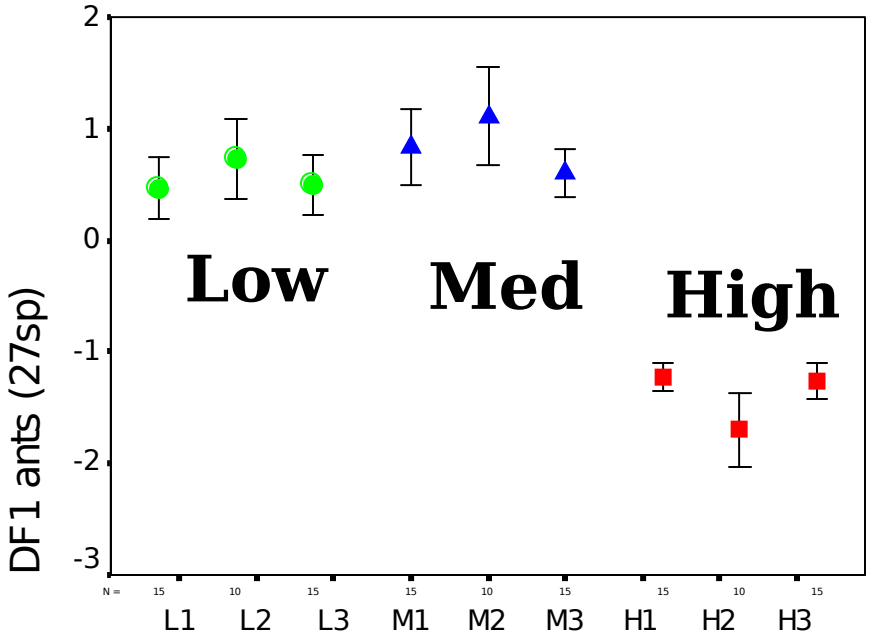
DF1

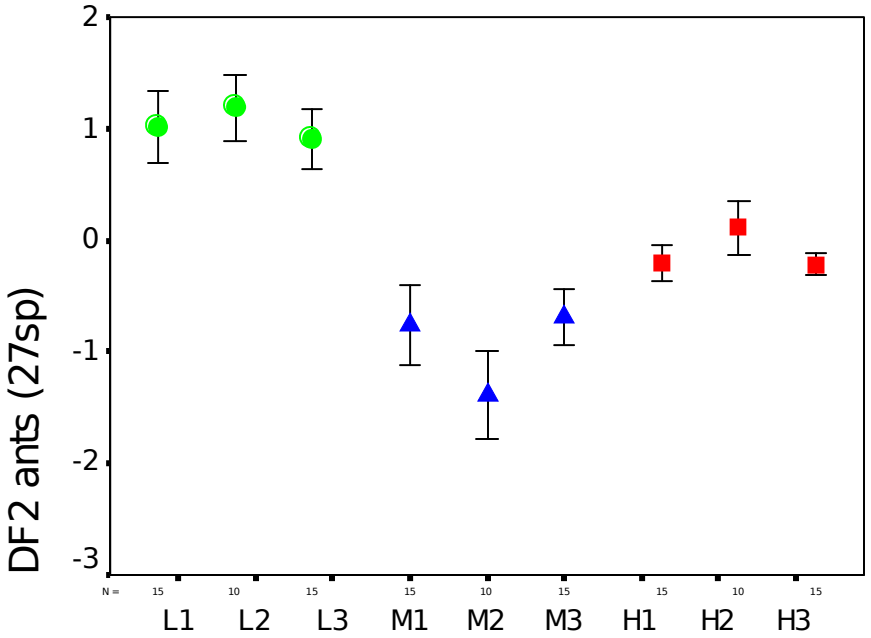
Mean with SE

DF2

Mean with SE

Ground Ant Community EIG
(2000, 2001, 2002)
27 Species in Analysis, N=13,774
Dorymyrmex smithi deleted from





DF1

Mean with SE

DF2

Mean with SE

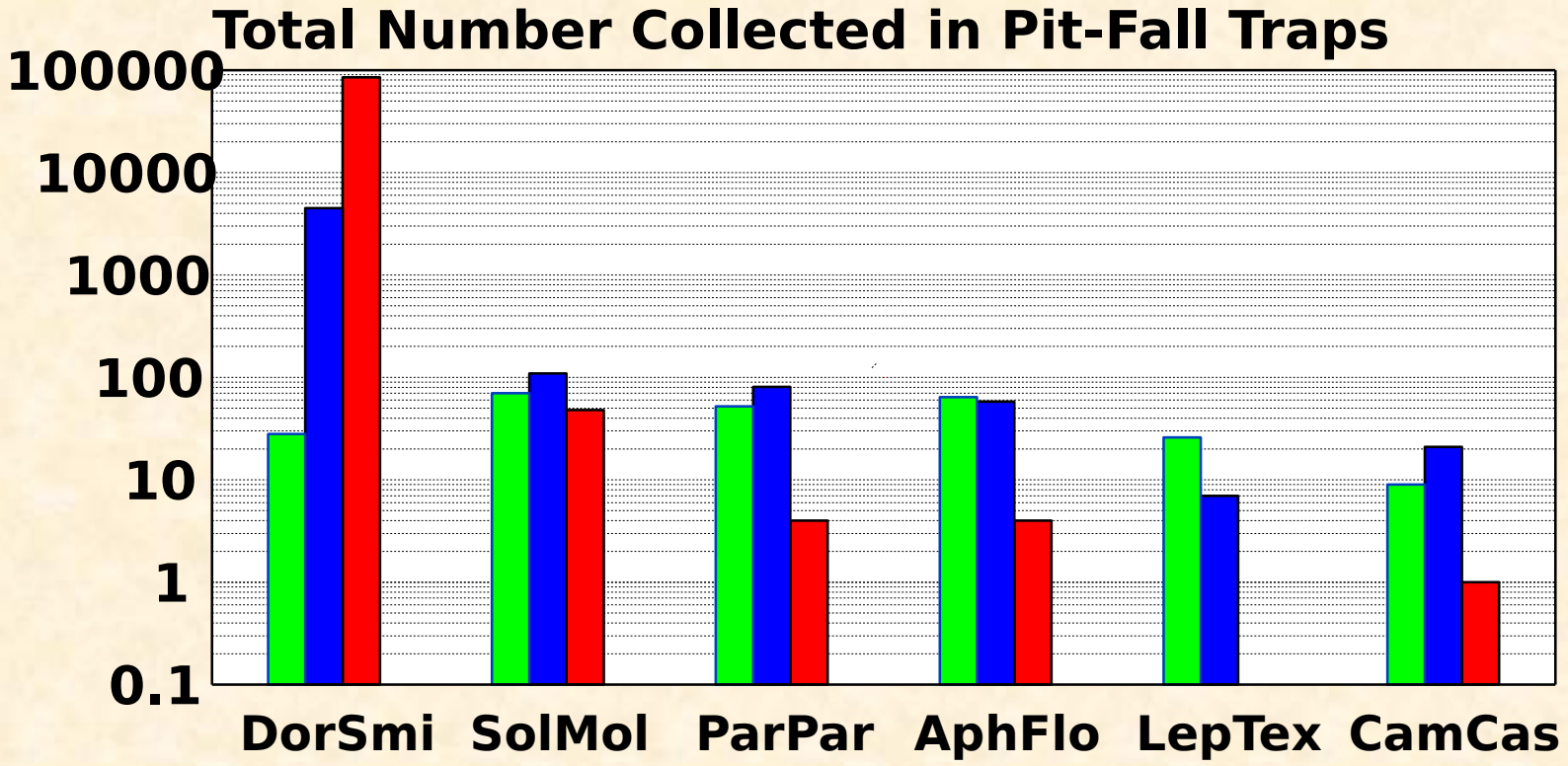
Ground Ant Community Ecological Indicator Guild

reduced from 28 original species to SIX species with Step-Wise DA

	(Abundance Rank)	N
Dorymyrmex smithi	(1)	(89429)
Solenopsis molesta	(9)	(227)
Paratrechina parvula	(12)	(137)
Aphaenogaster floridana	(13)	(126)
Leptothorax texana	(24)	(33)
Camponotus castaneus	(25)	(31)

Ant Ecological Indicator Guild

(2000, 2001, 2002)



Note LOG Scale

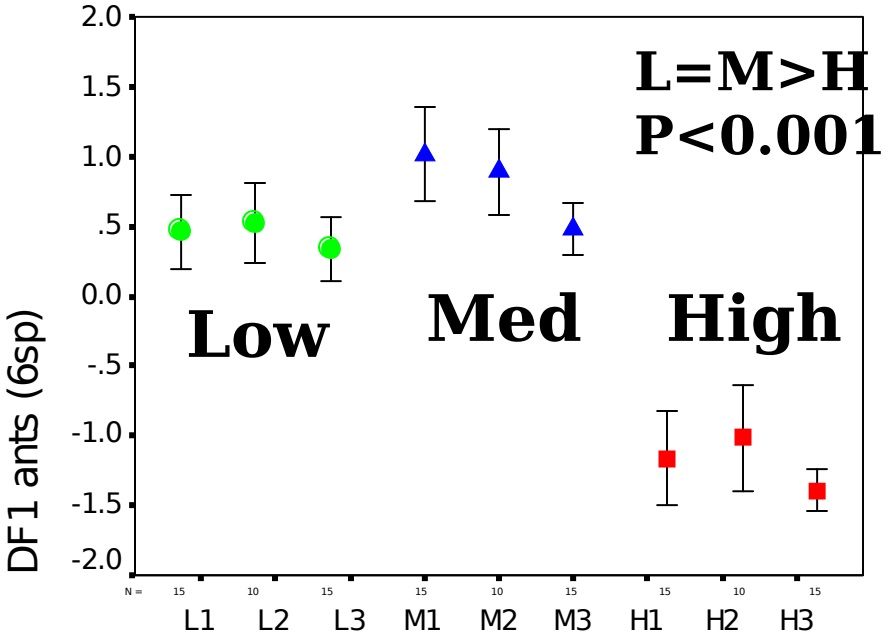
Ground Ant Community EIC

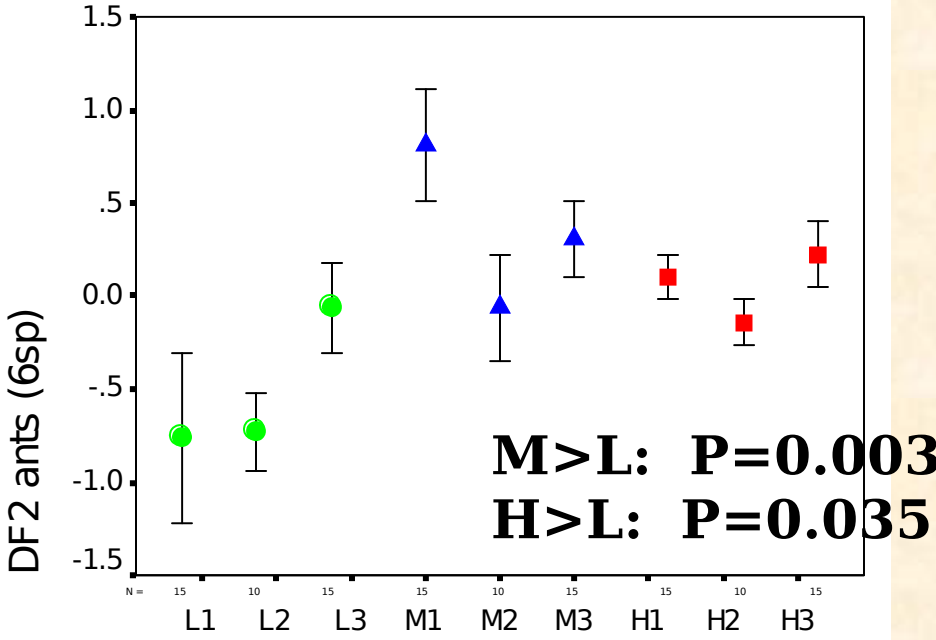
Based on Step-Wise Discriminant Analysis

2000, 2001, 2002

6 Species, N=89983

Dorymyrmex smithi = 99% of individuals





DF1

Mean with SE

DF2

Mean with SE

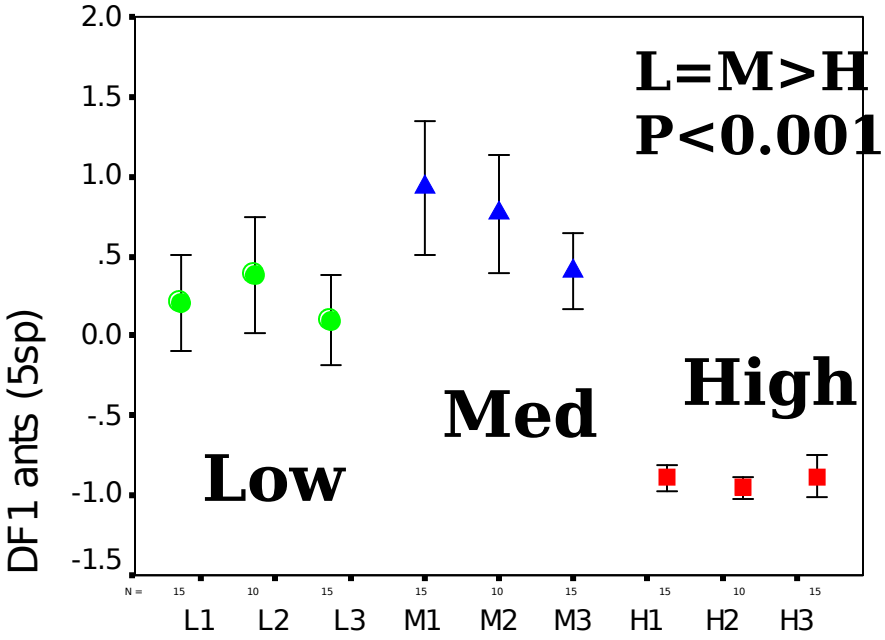
Ground Ant Community EIG

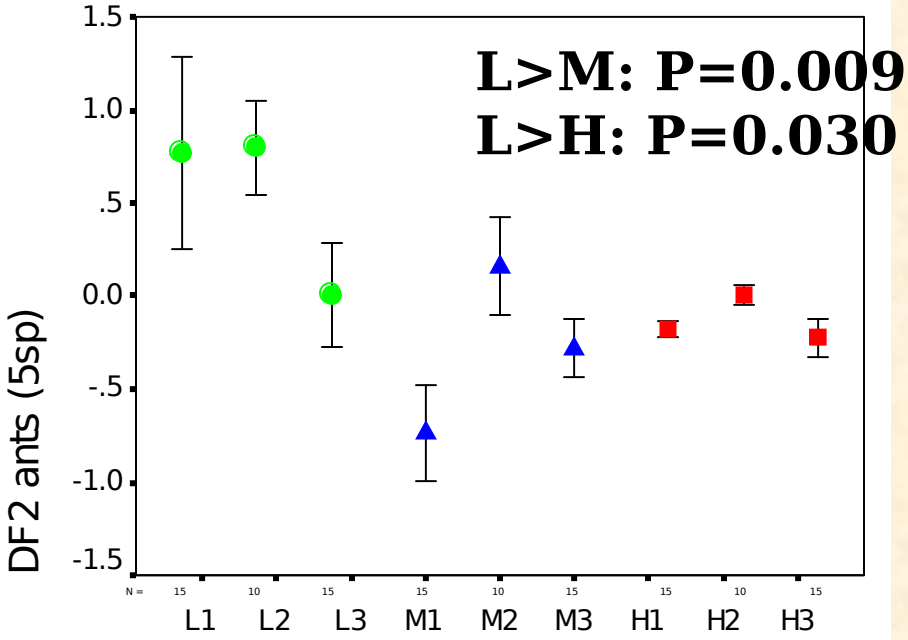
Based on Step-Wise Discriminant Analysis

2000, 2001, 2002

5 Species, N=554, *Dorymyrmex smithi* deleted

0.54% of all individuals, 0.62% Step-Wise





DF1

Mean with SE

DF2

Mean with SE

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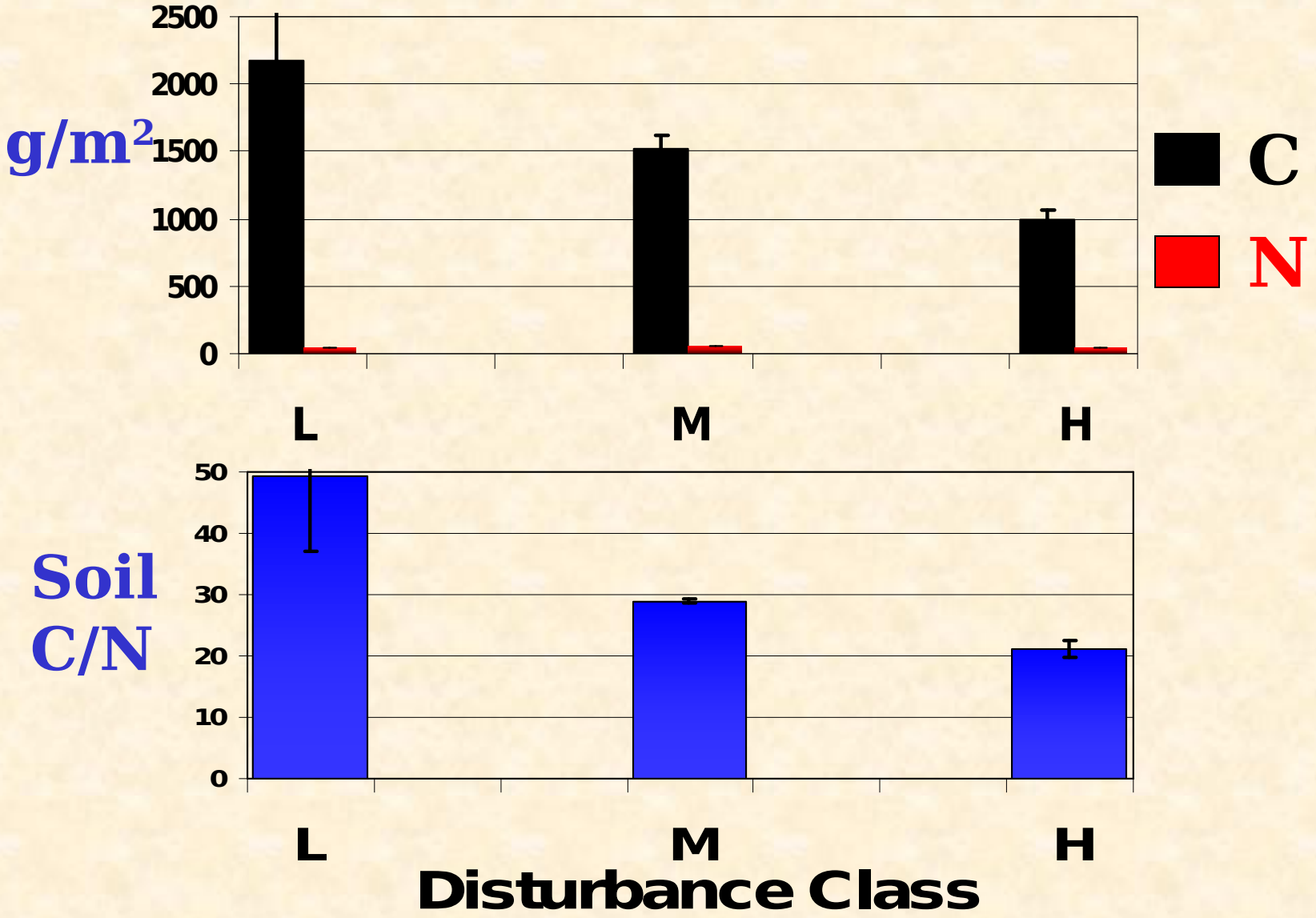
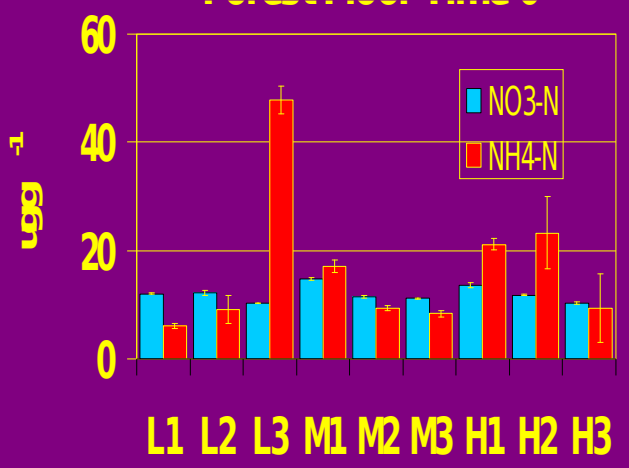
Soil Mineralization Potential as an Ecological Indicator

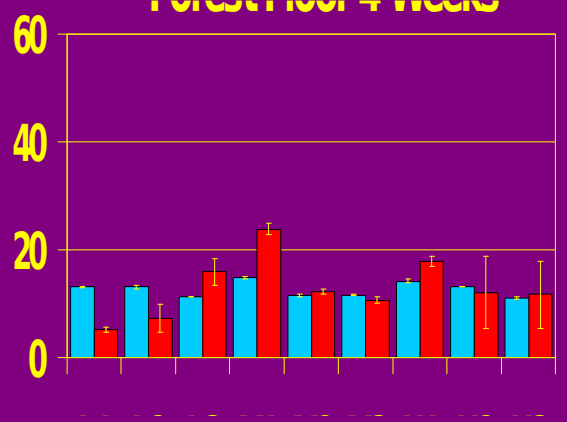
- **Undisturbed Forests**
  - High Soil Carbon Biomass
    = High Homeostasis = Ecosystem Resilience
  - Nitrogen in the form of NH_4
  - C/N > 30: favors Nitrogen retention by Decomposers
- **Disturbed Forests**
  - Decrease of NPP (Carbon Biomass)
  - C/N < 30: favors increase in Nitrifying Bacteria
  - Increase in Soil Mineralization
  - Increase in NO_3
  - Increase in Leaching of Nitrogen (NO_3)

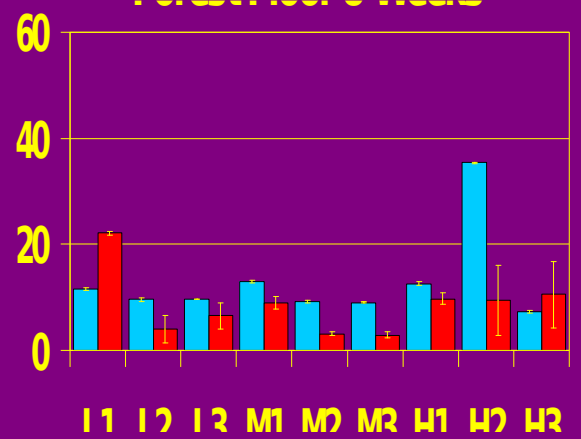
Soil Carbon and Nitrogen

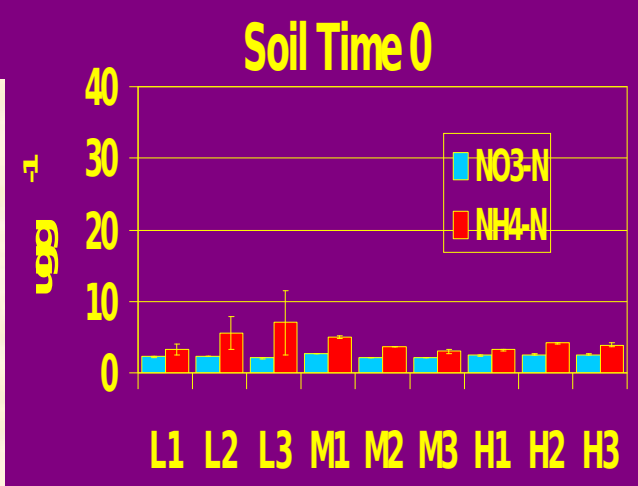


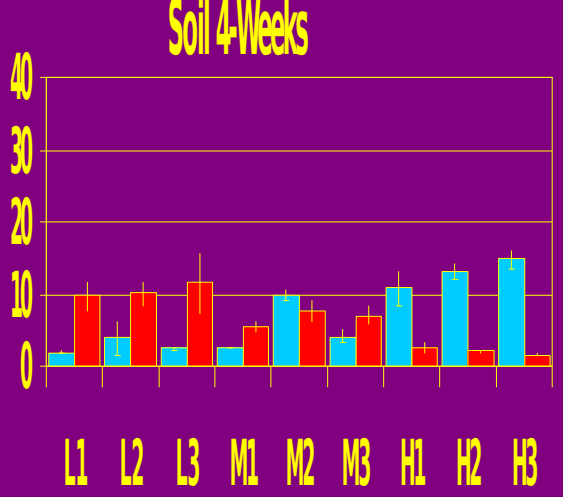
Forest Floor and Soil Incubation Results

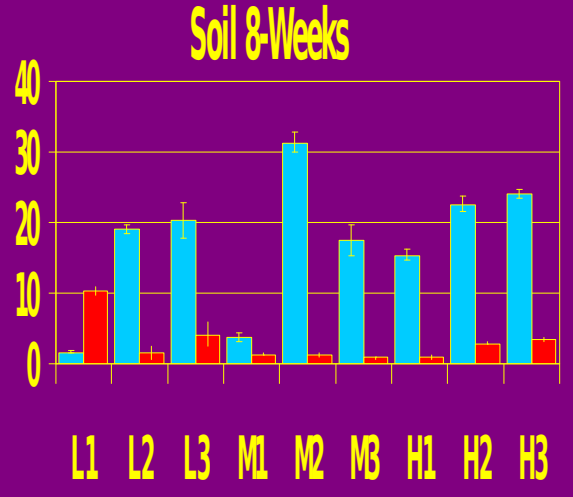












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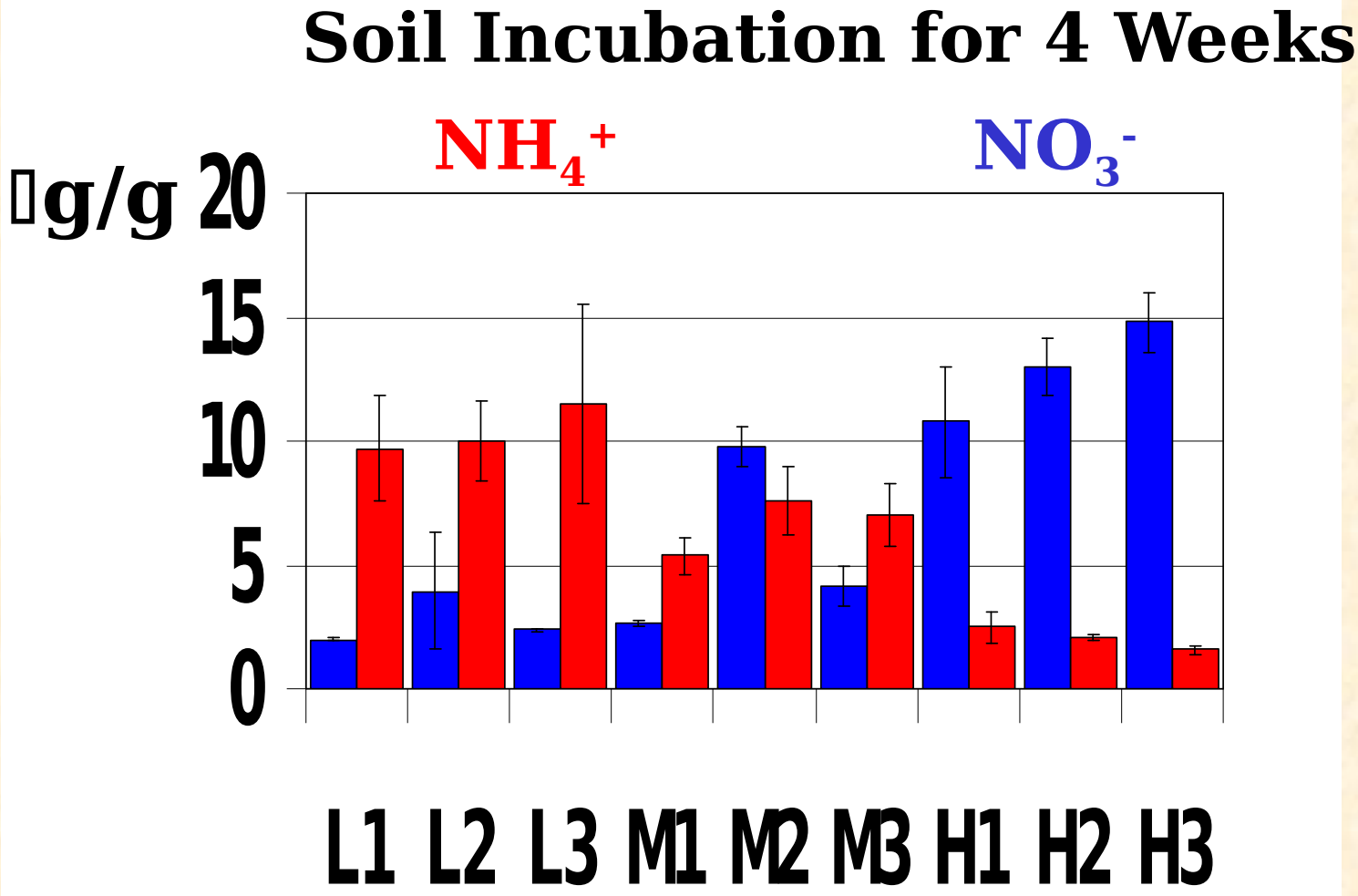
Soil Mineralization Potential



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Soil Microbial Community Ecological Indicator System

- **Main Drivers of Soil Nutrient Dynamics**
- **Link Nutrient Dynamics to Primary Producers**
- **Responsible for Decomposition**
- **Provides Monitoring Response to Perturbation**

Soil Microbial Parameters
Microbial Biomass Carbon

- **Snap-shot of microbial ecosystem component**
- **Evaluates influences on soil nutrient dynamics**
- **Driving variable for nutrient mineralization and immobilization**
- **Driving variable for decomposition rates**
- **Influences soil C/N ratios**

Soil Microbial Parameters

Functional Diversity and Activity

- **Fungal Community**
  - **Substrate Richness**

    Impact of factors to use a *variety* of carbon compounds
  - **Substrate Activity**

    Impact of factors on *rate* of carbon usage
- **Bacterial Community**
  - **As Above**

❖ **Influenced by density and species richness**

❖ **Assesses community level responses**

❖ **Links carbon use and soil organic matter**

❖ **Link with soil chemistry and MBC data**

❖ **Spatial and temporal analysis**

❖ **Directly contrasts sites and temporal sampling frames**

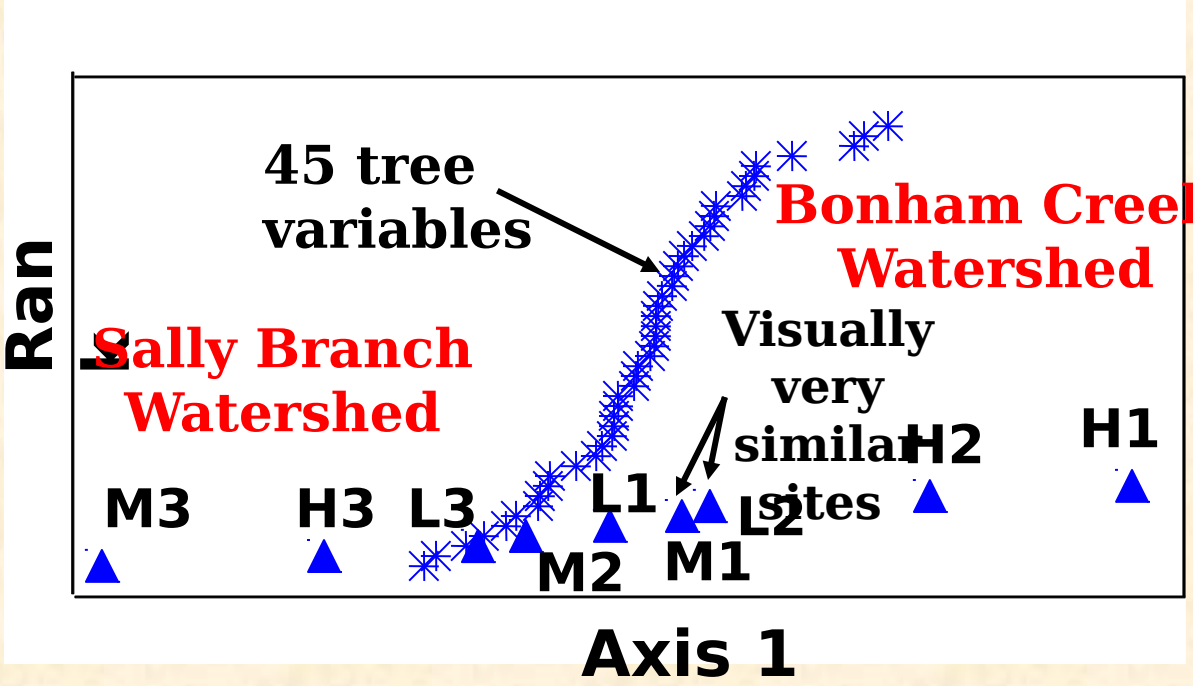
Microbial Community at 9 Sites Conclusions (2000, 2001, 2002)

- **Drought overrides:**
  - **Training Disturbance**
  - **Fire Regimes**
- **Microbial Biomass at upland High sites is unable to respond to the extent it does at Low and Medium sites**
- **Microbial Biomass dynamics at bottomland sites is more heterogeneous than in upland sites and is more independent of disturbance classes**
  - **Each site appears to be influenced (impacted) by up-slope conditions from military activities and fire**
- **Medium upland sites have the highest MBC and the most variability**
- **Bottomland sites do not differ substantially in annual MBC**

Microbial Community General Implications

- **Disturbance Class designations appear to depend on the specific nature of microbial parameters selected**
- **Similarity in MBC in Low and Medium sites suggests that microbial ecosystem processes are similar**
- **Microbial Dynamics are more closely related and relevant to nutrient conditions than to vegetation parameters**

NMS Ordination of 9 Sites Based on Tree Communities (Floristics)



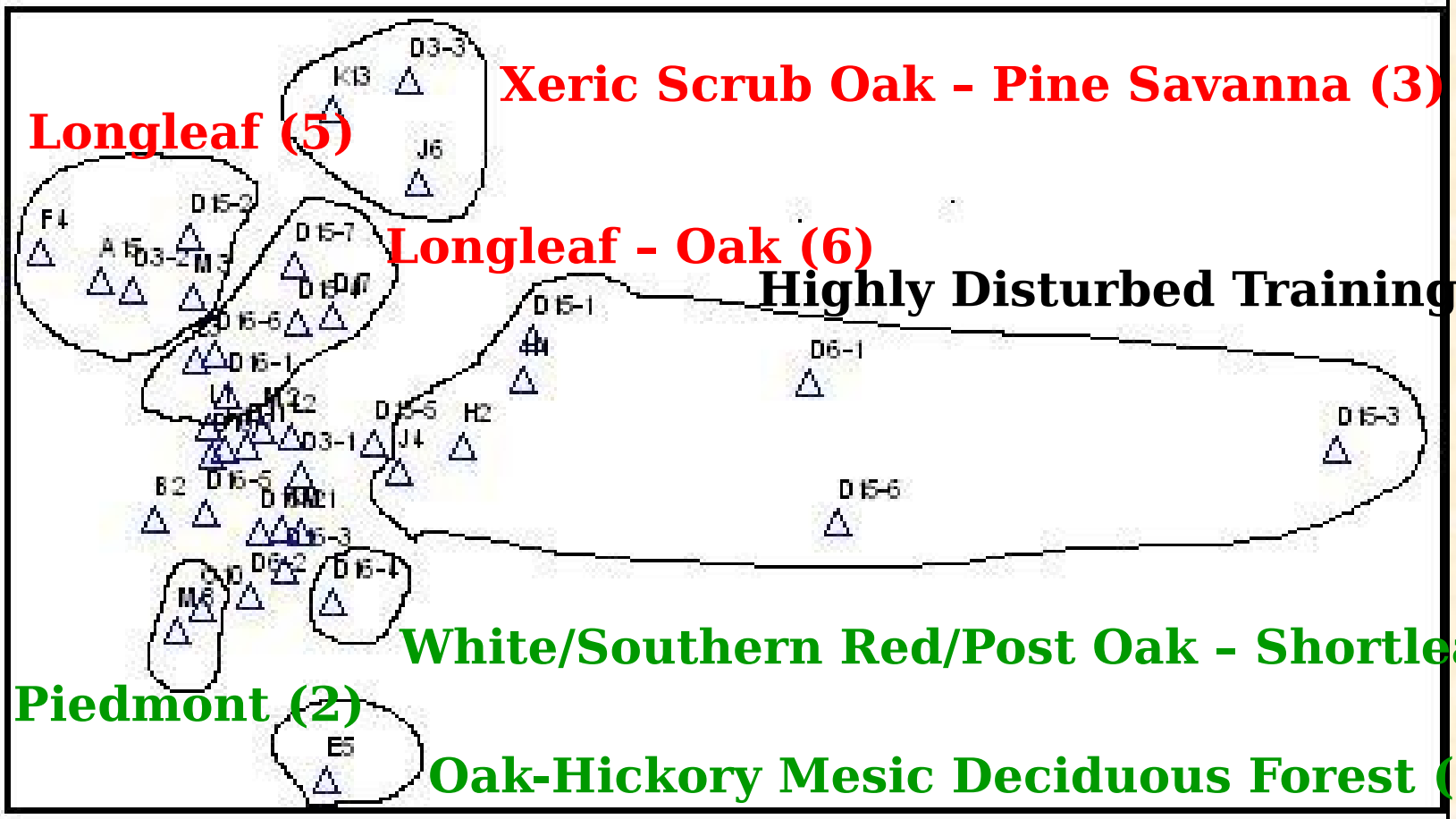
15 Tree Species: density, mean DBH, std. dev. DBH

Research Approach 2003 - 2004

- **Validation & Refinement of EIGs**
  - **40 Sites Selected (including original 9)**
    - **GIS Themes and Ground Truthing: SEMP Research Sites, Land Cover, Forest Stand Ages**
    - **Upland Forest - Full Extent of available habitats:**
      - **Military Training Disturbance**
      - **Forest Stands – Tree Communities – Soils**
      - **Unique Ecological Areas (7-8 uplands): Sites in 6**
  - **Field Data: Promising Environmental Variables**
  - **Sampling Plots: 4 hectare**
- **Multivariate & Structural Equation Modeling**
  - **Associate Ecological Indicator Guilds along a Continuous Landscape Disturbance Gradient**
- **Identify Ecological Indicator Ensemble**

NMS Ordination of 40 Sites Based on Basal Areas of 26 Tree Species

10 Classes independently derived with Cluster A



NMS Ordination of 40 Sites Based on Basal Areas of 26 Tree Species

10 Classes independently derived with Cluster A

Three Classes Clumped in NMS Ordination Space

- **Loblolly/Shortleaf - Hardwoods**
  6 sites
- **Mixed Pine – Oak – Hickory: Loblolly Dominant**
  7 sites
- **Mixed Pine – Southern Red Oak**
  2 sites: one pine dominant, one hardwood dominant

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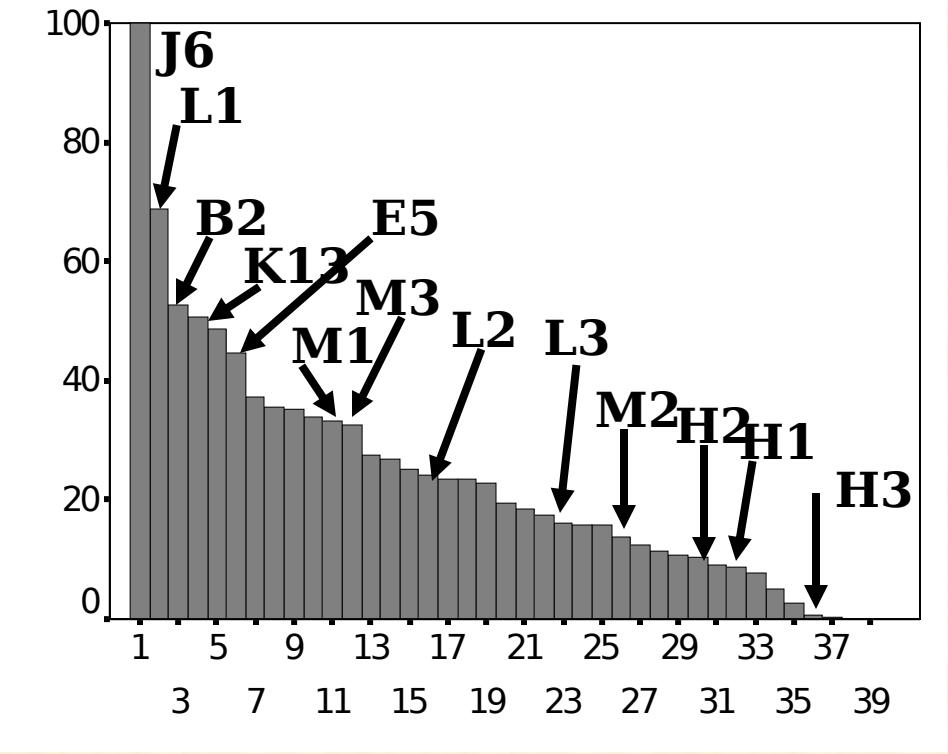
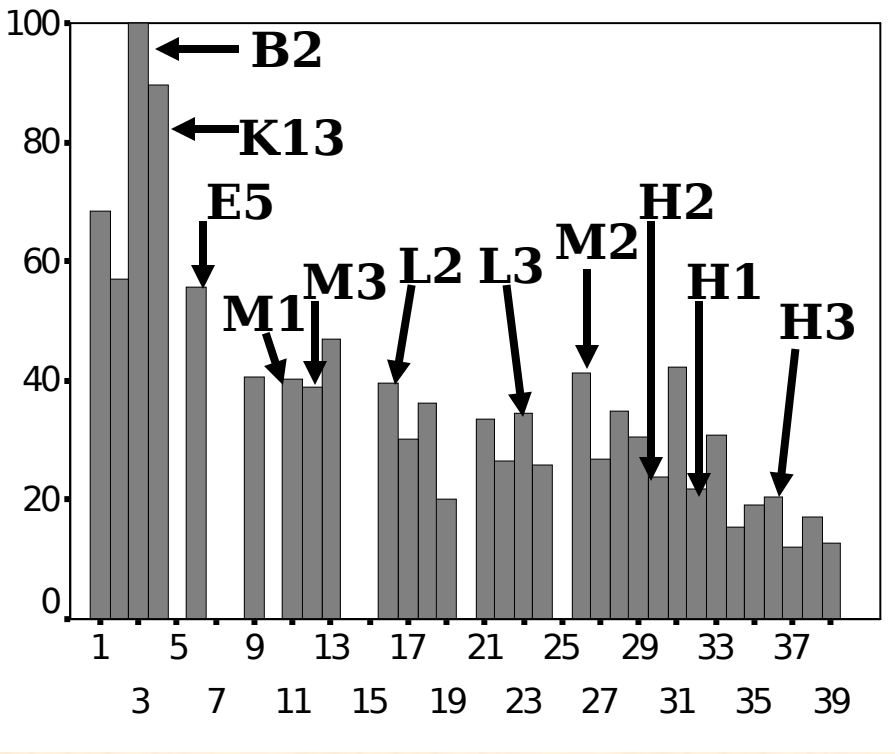
Soil A-Horizon Depth



Soil Compaction

Relative Scale



Sites Ranked by Soil A-Horizon Depth

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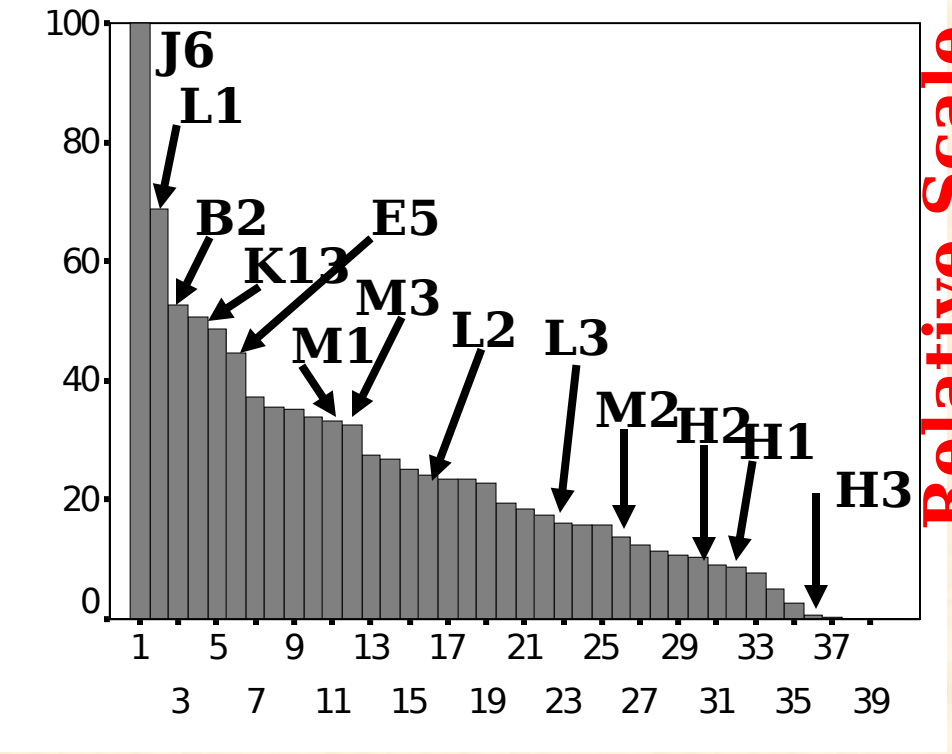
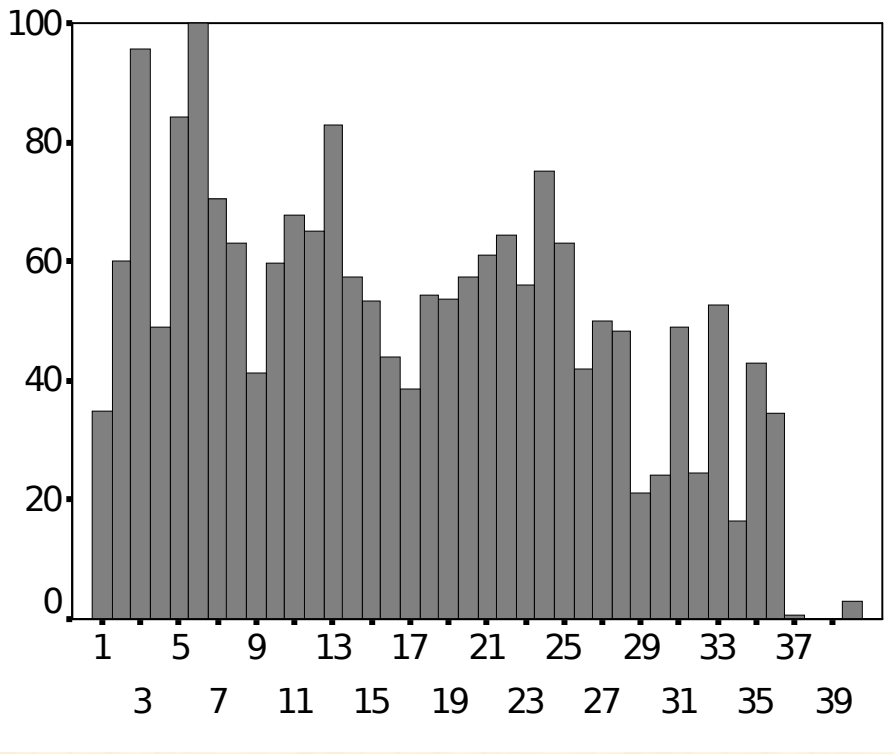
Soil A-Horizon Depth



Relative Scale

Canopy Cover



Sites Ranked by Soil A-Horizon Depth

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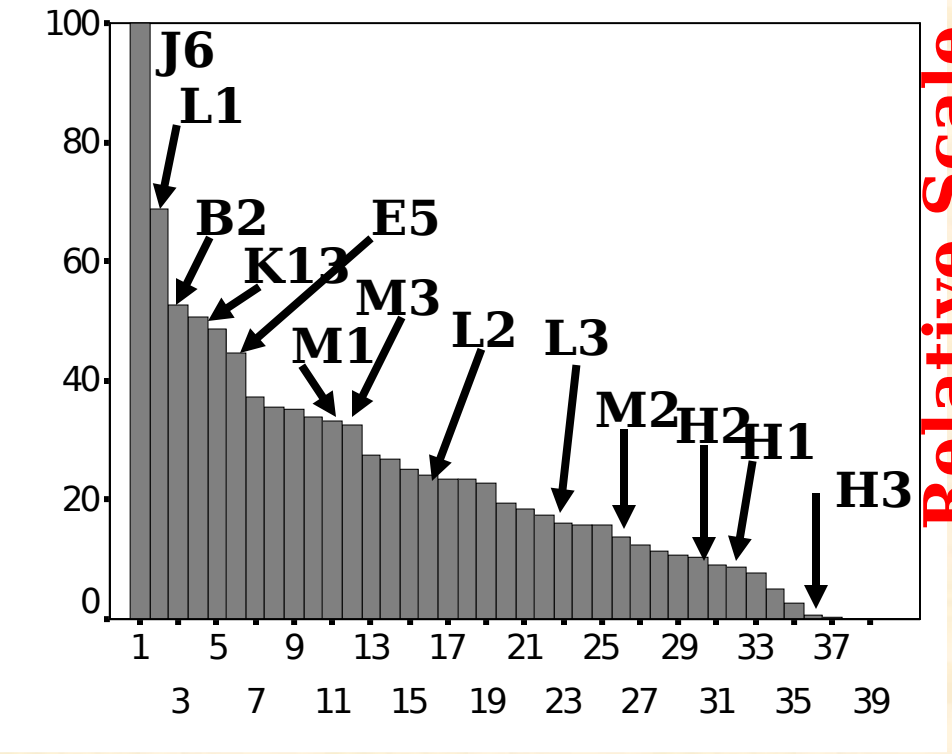
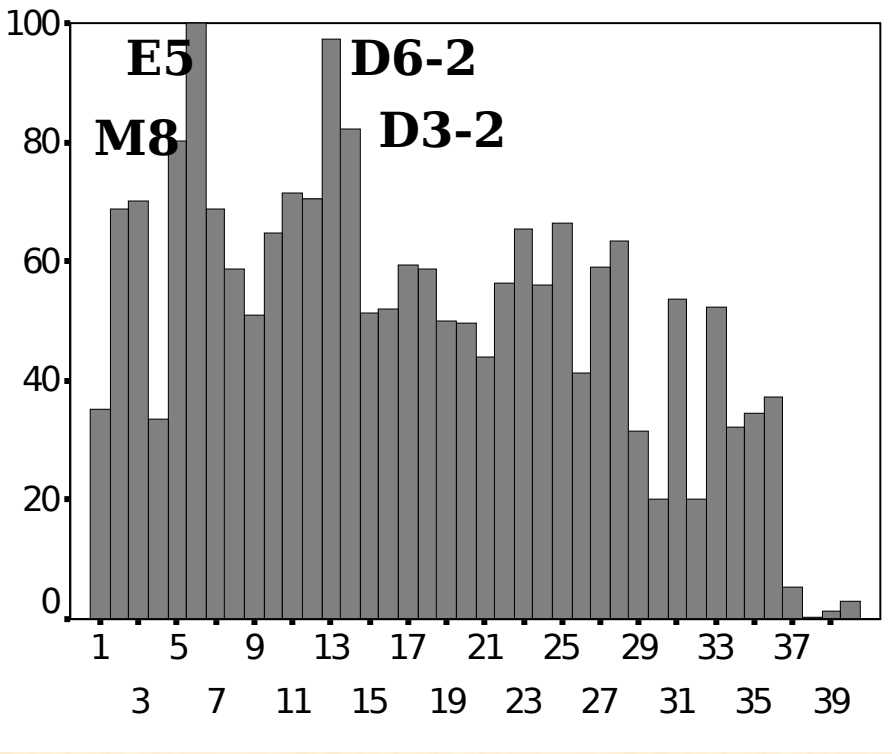
Soil A-Horizon Depth



Relative Scale

Basal Area (Cruz-All m



Sites Ranked by Soil A-Horizon Depth

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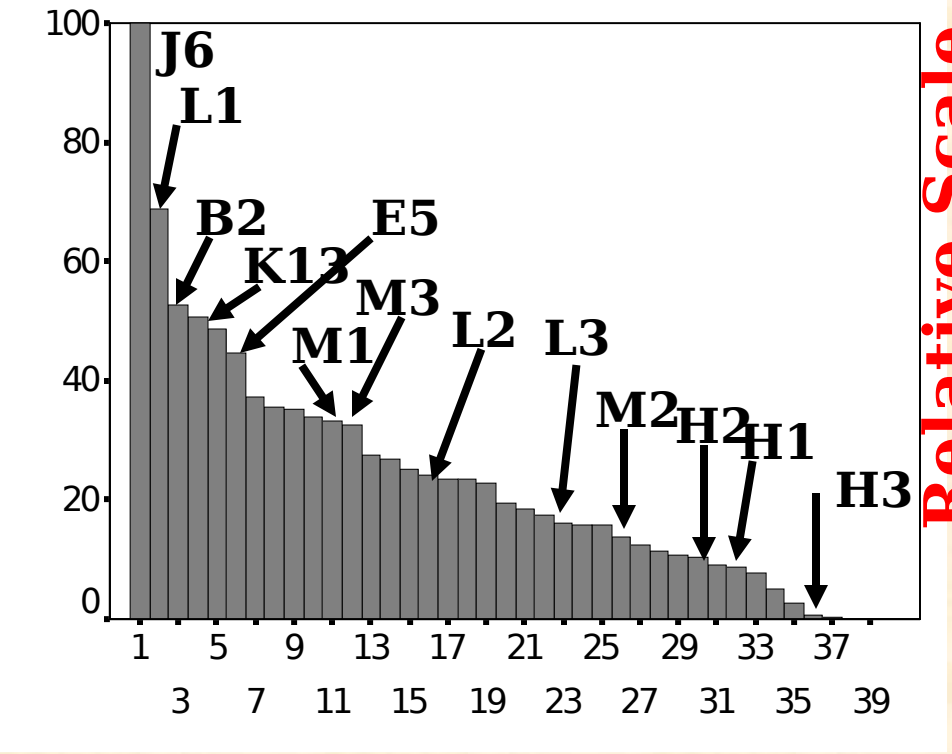
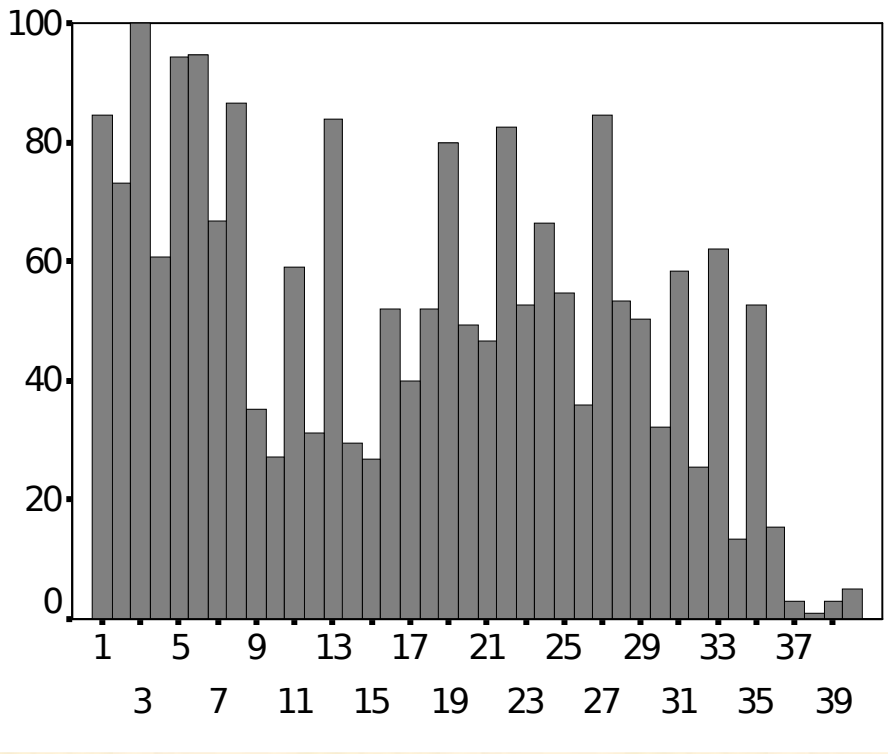
Soil A-Horizon Depth



Relative Scale

Tree Density

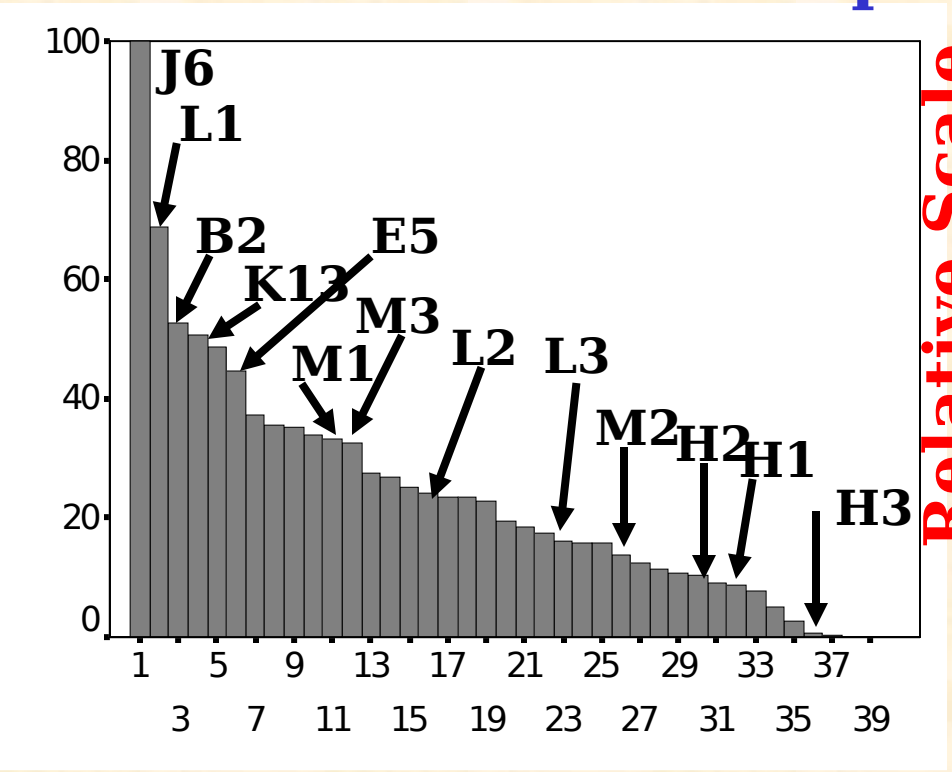


Sites Ranked by Soil A-Horizon Depth

DoD EPA DOE SERDP
Strategic Environmental Research and Development Program

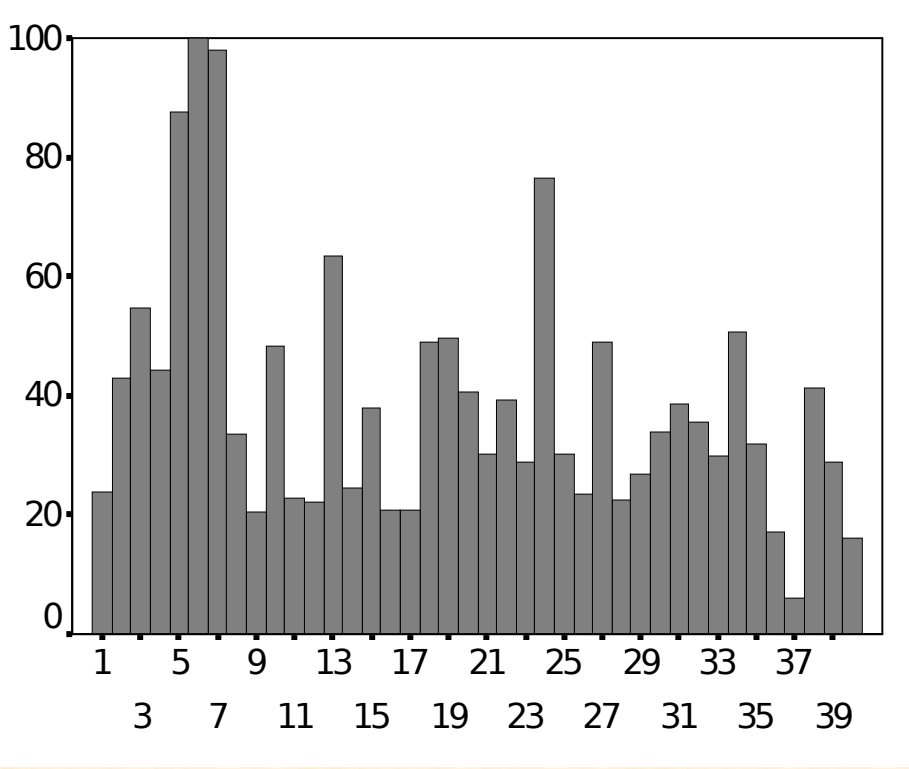
Prescott College

Soil A-Horizon Depth



Relative Scale

Microbial Carbon Bion



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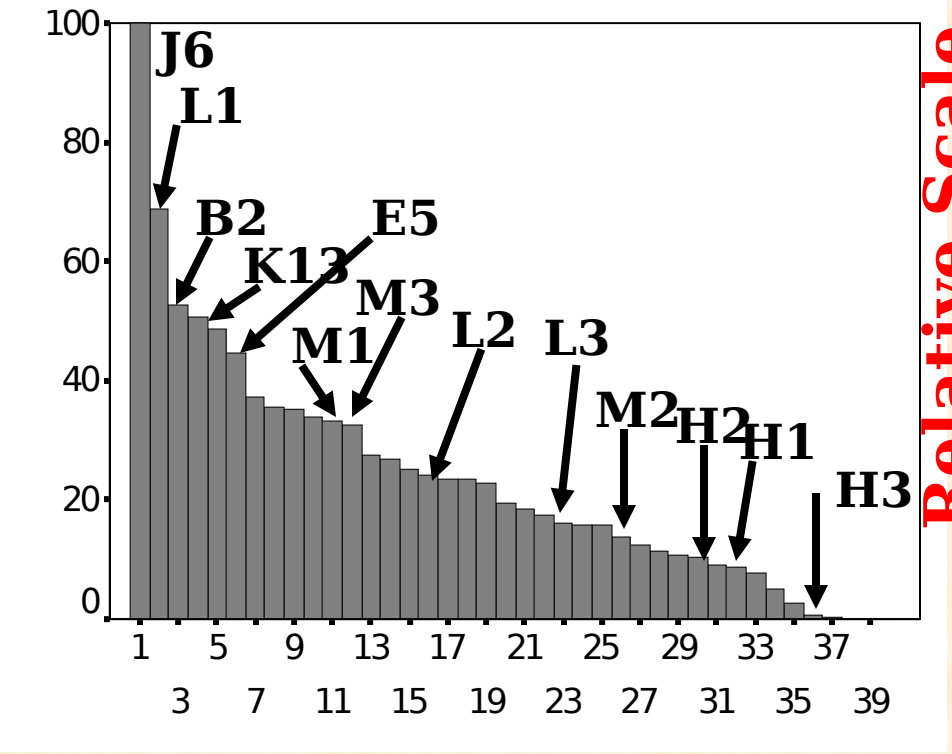
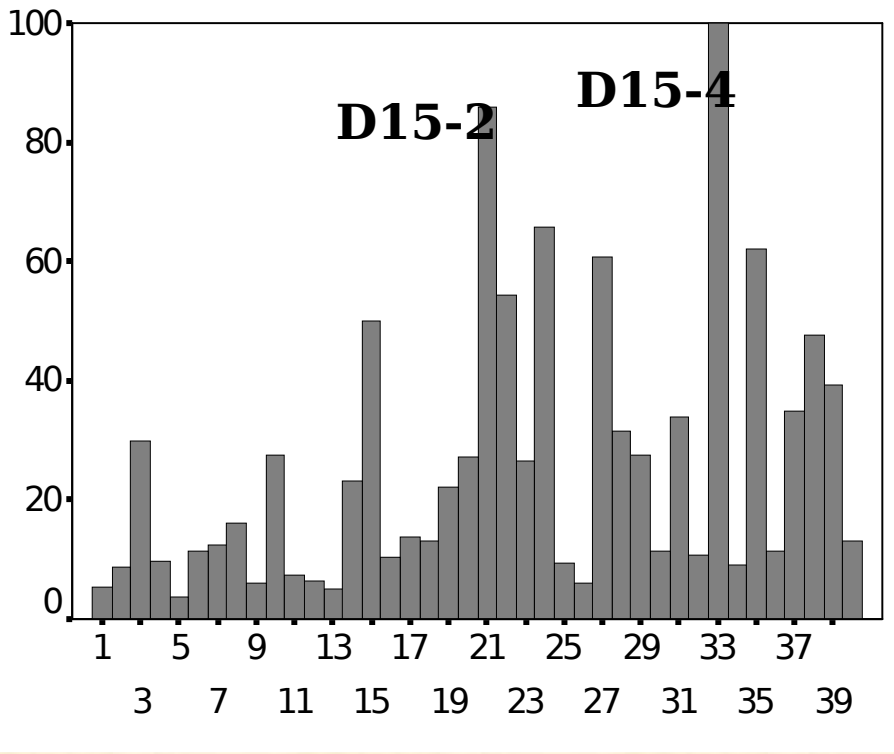
Soil A-Horizon Depth



Relative Scale

NH_4/NO_3



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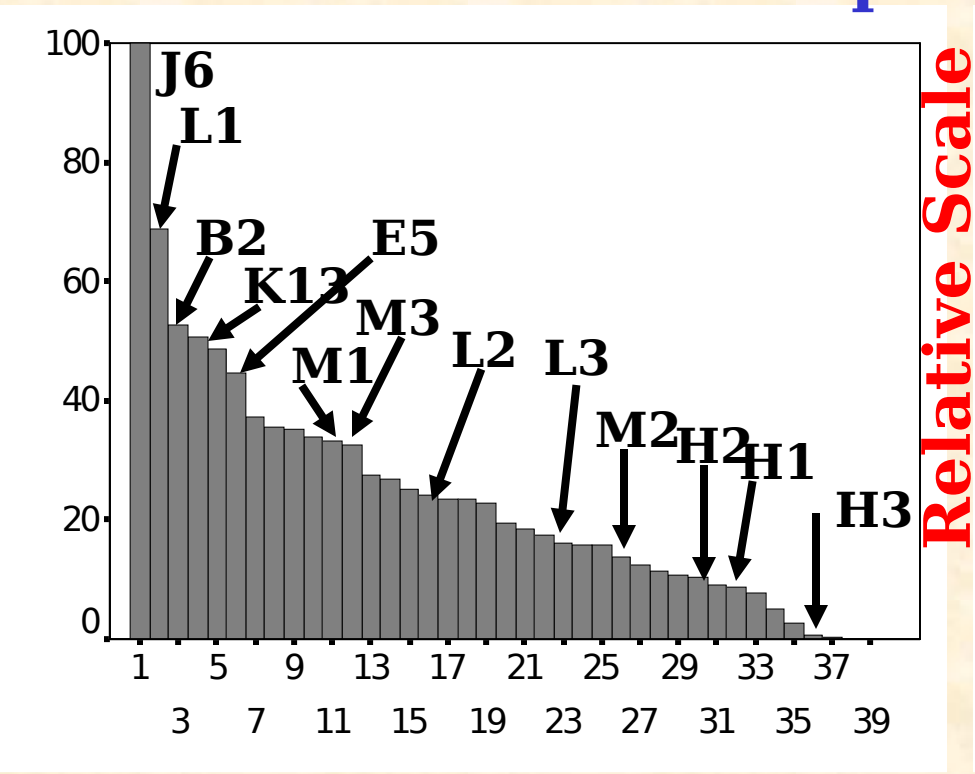
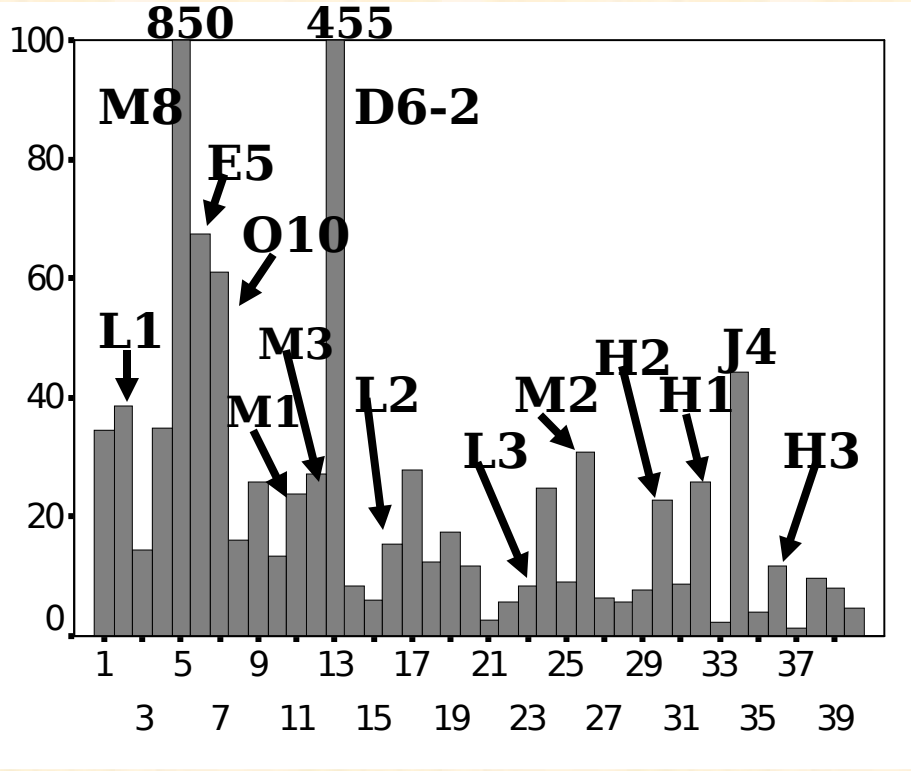
Soil A-Horizon Depth



Relative Scale

$MBC/NH_4_NO_3$ ratio



Sites Ranked by Soil A-Horizon Depth

Pearson Correlation (two-tailed)

	Soil Comp.	Can Cov.	BA (max)	BA (dbh)	Tree Den.	MCB	NO_3	NH_4	NH_4/NO_3
A-Horizon	**-.69**	**.50**	**.46**	**.49**	**.60**	NS	**.42**	NS	-.38*
Soil Comp.		**-.72**	**-.70**	**-.73**	**-.70**	NS	NS	NS	NS
Canopy Cover			**.91**	**.91**	**.79**	**.60**	NS	NS	NS
BA (max)				**.96**	**.68**	**.48**	.38*	NS	NS
BA (dbh)					**.66**	**.52**	.37*	NS	NS
Tree Density						**.54**	.34*	NS	NS
MBC							.36*	NS	NS
NO_3								**.41**	NS
NH_4									**.68**

Correlations in BOLD: P < 0.01
Correlations with * : P < 0.05
NS = Not Significant: P > 0.05

Conclusions

- The Guild Approach using Discriminant Analysis has been useful in identifying classes of variables or species that possess a similar response to a Disjunct Landscape Disturbance Gradient, and therefore show promise as Ecological Indicators
  - Habitat metrics
  - Ground Cover
  - Ground Ant Community
  - Soil Chemistry
  - Microbial Community
- DA demonstrated to optimize/minimize sampling effort & costs
- Quantifies sampling effort versus desired accuracy
- Nonmetric Multidimensional Scaling (NMS) ordination shows excellent potential for identifying and ranking underlying community structure in a Landscape Disturbance Gradient

Publications and Presentations

- **Manuscripts**
  - Accepted and In Press 3
  - Submitted 3
  - Submission within 2 months 8
  - Others in Active preparation 8
- **Presentations and Posters**
  - ESA 2002-20035
  - Others 2001-2003 11
  - Student Posters 2001-20023

Acknowledgements and Thanks

- **Fort Benning Staff and Researchers**
  - **Hugh Westbury – SEMP Coordinator**
  - **John Brent – Environmental Chief**
  - **Pete Swiderek – Wildlife Manager**
  - **Range Control Personnel**
- **SERDP and TAC Personnel**
- **U.S. Army – ERDC**
  - **Champaign, IL and Vicksburg, MS**

Slides for Background and Additional Information

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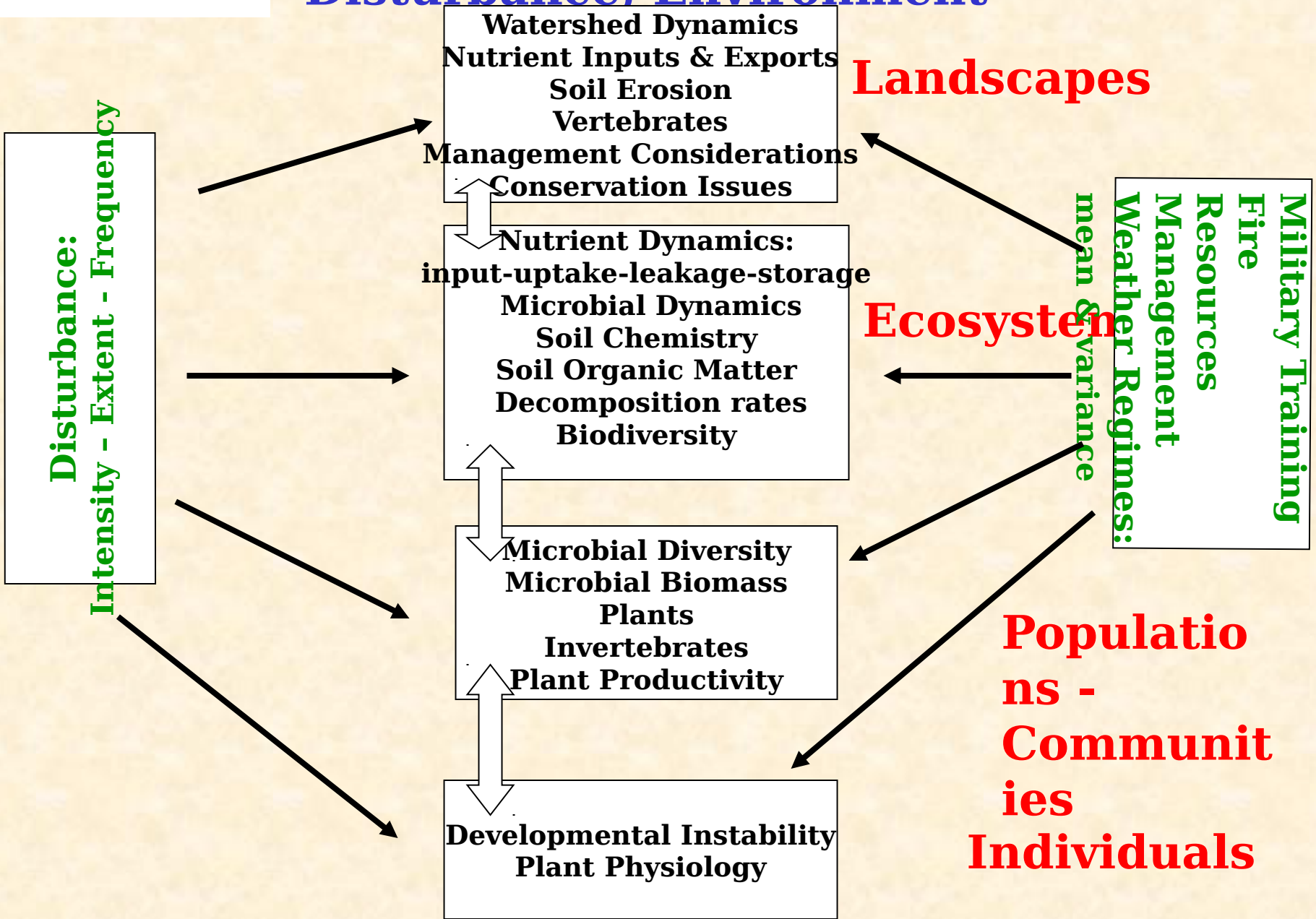
Application of Ecological Indicators for Military Land Management

- Training sustainability
- Ecosystem maintenance and sustainability
- Long-term productivity
- Multiple-use decisions and requirements
- Conditions & Trends in natural resources
- Timing and success of restoration efforts
- Environmental monitoring
- Legal mandates

Integration: Ecological Indicators, Disturbance, Environment



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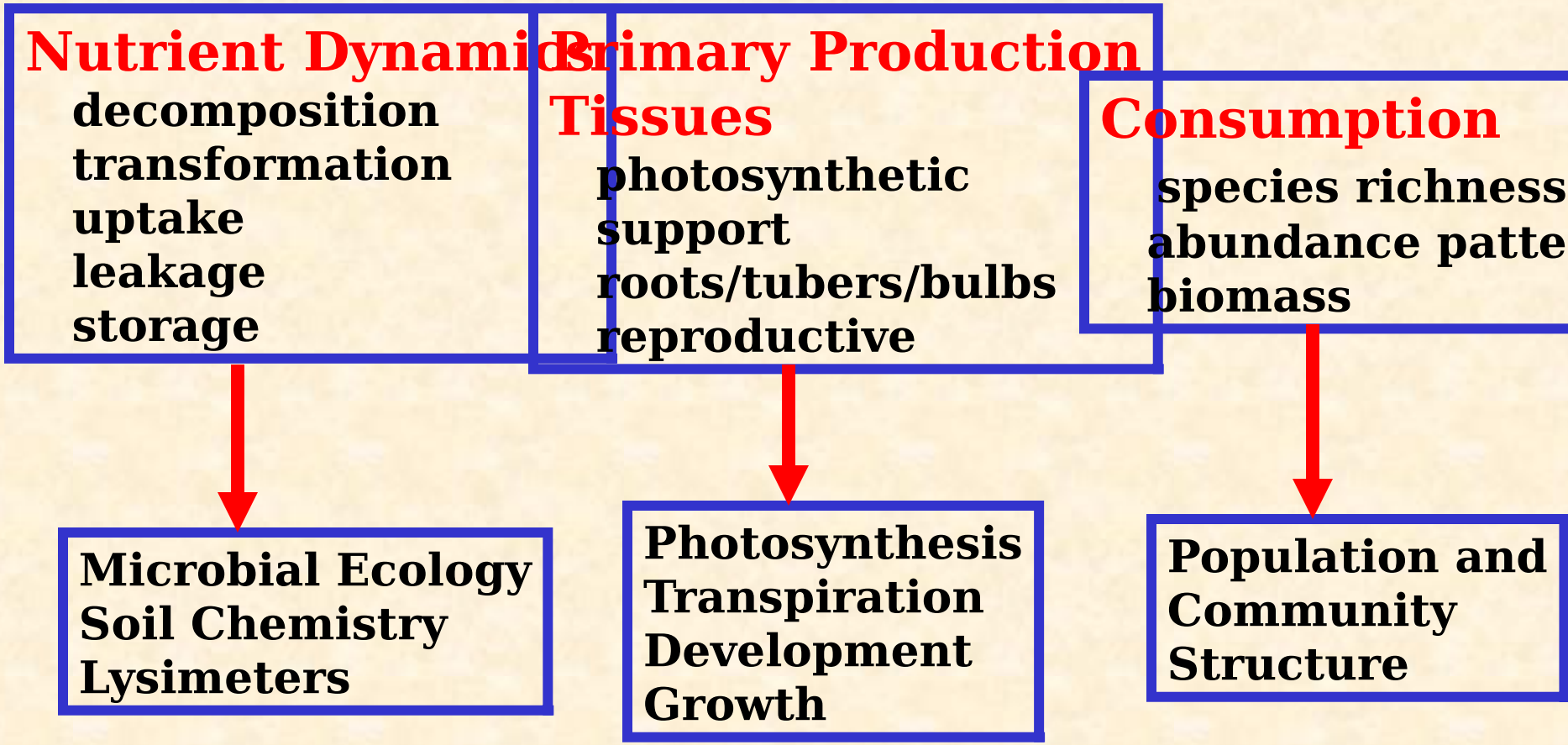
Ecological Processes

Linking Below Ground and Above Ground Components



Field and Lab Measurements

Disturbance to Ecological Systems are Complex